

DEVELOPMENT OF AN IN-ROW SUBSOILER ATTACHMENT TO REDUCE SMEARING

R. L. Raper, E. B. Schwab

ABSTRACT. *Hardpans are prevalent throughout the southeastern United States and frequently restrict root development thus making crops susceptible to short-term droughts. In-row subsoiling has become the tillage tool of choice for alleviation of this compacted soil condition in Coastal Plain soils. However, in many soils with higher amounts of clay, smearing occurs near the bottom of the shank, thus trapping the roots in the subsoiled channel. A novel approach to disturb the bottom of the smeared zone was evaluated. Results of three experiments involving corn and cotton grown in coarse- and fine-textured soil types indicate that the use of a shank attachment designed to alleviate smearing may increase crop yields in fine-textured soils where soil smearing is common. Excessive depths of in-row subsoiling were not found to be beneficial to the crops investigated and required significantly more draft force, resulting in higher fuel requirements.*

Keywords. *Subsoiling, Strip-tillage, Soil compaction, Draft, Cone index, Bulk density, Cotton, Corn, Depth.*

In-row subsoiling is an effective tillage operation that is frequently used in the southeastern United States to allow producers to reduce the effects of soil compaction while maintaining adequate amounts of crop residues on the soil surface (Campbell et al., 1974; Box and Langdale, 1984; Raper et al., 1994; Raper et al., 1998; Busscher and Bauer, 2003; Raper, 2005; Raper and Bergtold, 2007). However, the success of this operation is not uniform as some soils that suffer from soil compaction do not respond to in-row subsoiling. For example, the fine-textured alluvial soils of the Tennessee Valley respond more favorably to cover crops than in-row subsoiling as a primary method to reduce soil compaction (Touchton et al., 1986; Raper et al., 2000a; Raper et al., 2000b; Schwab et al., 2002). It is hypothesized that soil smearing near the bottom of the trench caused by the in-row subsoiling operation may be responsible for limiting root growth into deeper soil profiles. Evidence of this is sometimes seen by excavating plots where subsoiling has been conducted. Roots will grow rapidly downward to the bottom of the trench and then will turn horizontally along the path of the subsoiler until they can find a crack or void and can escape.

Soil smearing has been noted to cause problems in agricultural production, particularly related to planting operations. Iqbal et al. (1998) found that planter attachments,

which included single- and triple-discs, were useful in reducing the amount of soil smearing occurring on the seed sidewall. They noted that more roots grew parallel to the soil surface with no-coulter and single-coulter treatments than with a triple-coulter treatment, especially when soil measurements indicated that soil smearing had occurred.

Soil smearing is not confined to the planting operation, however. Fielke (1996) also found visual evidence of soil smearing when tillage tools were used in a soil bin, mostly due to the use of blunt-edge tillage tools. They found an increase in cone index near the tillage tool and hypothesized that forward soil movement and smearing was responsible for this increase. Gaultney et al. (1982) noted that plowpans may be the result of downward reaction forces and the smearing effects of the plow sole sliding over the soil. Tessier et al. (1997) investigated a modified one-way disk as an alternative to a moldboard plow and noted the absence of a soil smearing zone below the modified implement.

If soil smearing could be avoided, perhaps the use of in-row subsoiling might be a valuable tool for producers who have a soil compaction problem in fine-textured soils. The purpose of this research project was to determine if an attachment mounted just below and to the rear of a subsoiler shank would sufficiently eliminate soil smearing.

Therefore the objectives of these studies were:

- Evaluate the effect of an attachment mounted on a subsoiler shank on soil properties, cotton and corn yields, and draft forces, and
- Evaluate the effect of in-row subsoiling depth on soil properties, cotton and corn yields, and draft forces.

METHODS AND MATERIALS

Three experiments were conducted to evaluate the potential of the subsoil shank spur attachment. The first experiment was begun in the spring of 2004 at the E.V. Smith Research Center in Shorter, Alabama (south-central Alabama) on a Compass loamy sand soil (coarse-loamy, siliceous, subactive, thermic Plintic Paleudults) which is a

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The authors are **Randy L. Raper**, ASABE Member Engineer, Agricultural Engineer, Lead Scientist, USDA-ARS, Dale Bumpers Small Farms Research Center, Booneville, Arkansas; and **Eric B. Schwab**, Agronomist; USDA-ARS National Soil Dynamics Laboratory, Auburn, Alabama. **Corresponding author:** Randy Raper, USDA-ARS, Dale Bumpers Small Farms Research Center, 6883 So. St. Hwy 23, Booneville, AR 72927; phone: 479-675-3834 ext. 324; fax: 479-675-2940; email: randy.raper@ars.usda.gov.

Coastal Plain soil commonly found in the southeastern United States and along the Atlantic coast of the United States. These soils are typically prone to subsoil compaction and usually require annual in-row subsoiling. This experiment focused on a continuous cotton production system. A second experiment was begun in 2005 to evaluate continuous cotton production system at the Tennessee Valley Research and Extension Center in Belle Mina, Alabama (north Alabama) on a Decatur silt loam (Fine, kaolinitic, thermic Rhodic Paleudults) which is a loess soil near the Tennessee River in north Alabama. This soil is not as easily compacted as the Coastal Plains soil, but could be more prone to smearing with its higher clay content. A third experiment was started in 2005 at the same south-central Alabama location to evaluate the effect of the spur attachment on a continuous corn production system. It was thought that the fibrous rooted corn systems could potentially have a benefit perhaps unseen by the tap-rooted cotton plants. These multiple studies were designed to determine the effect of an in-row subsoiler attachment at two different depths in a conservation tillage system.

The experimental design was a randomized complete block with a 2x2 factorial arrangement of treatments augmented with an additional control treatment of no-tillage for the Tennessee Valley region. A no-tillage treatment was added for this northern region because their soils often do not require in-row subsoiling and the use of a cover crop is usually sufficient to cure problems associated with soil compaction (Raper et al., 2000b). The two factors investigated were: 1) tillage depth (shallow tillage 20 cm, and deep tillage 33 cm) and 2) deep tillage attachment (with the in-row subsoiler attachment and without in-row subsoiler attachment). In the Compass loamy sand soil (USDA-NRCS, 2009a), both depths of tillage extend into the E horizon which normally extends from 20 to 40 cm in this soil type. In the Decatur silt loam soil (USDA-NRCS, 2009b), the shallow tillage depth extends into the Bt1 horizon (18-30 cm) while the deeper tillage depth extends into the Bt2 horizon (30-50 cm). Each treatment was replicated four times (20 plots) at each location. The in-row subsoiler used was a Kelley Manufacturing Company's (Tifton, Ga.) Rip/Strip in-row subsoiler with a straight standard 45° shank. This in-row subsoiler was used for all treatments that received deep tillage (with and without the attachment).

A standard 17-tooth sprocket with outside diameter of 9 cm (Baum Hydraulics Corp., Omaha, Nebr.) was used for the spur and was mounted to the rear of the shank for field use (fig. 1). This attachment was commonly referred to as a spur. A United States Patent has been applied for on the subsoiler shank attachment (Raper and Schwab, 2006). A magnetic proximity sensor was also mounted to the bracket holding the spur to ensure adequate rotary velocity as the implement traveled forward.

The plots for experiment 1 and 2 were four, 100 cm rows wide (4 m) by 15 m long. For experiment 3, the plots were four, 0.76 m rows wide (3.05 m) by 15 m long. After the cotton and corn were harvested in the fall, a rye cover crop was planted in experiments 1 and 2 and clover cover crop in experiment 3 until the following spring when the cover crop was chemically and mechanically terminated. Chemical termination is the normally recommended practice of cover crop termination and provides excellent results. For rye before cotton, glyphosate at a rate of 1.12 kg ai (active

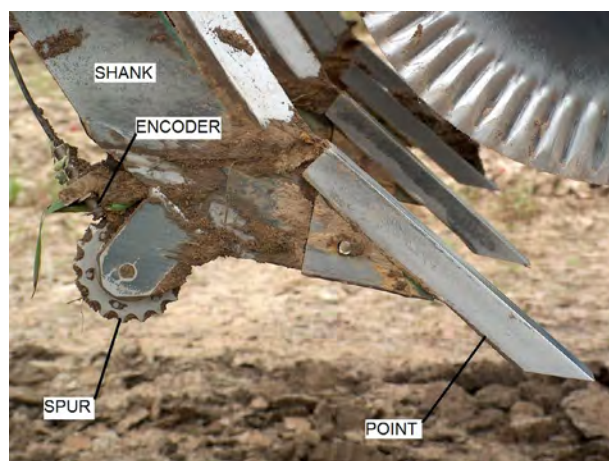


Figure 1. Photo of the in-row subsoiler attachment mounted just below and to the rear of the shank used in the study.

ingredient)/ha was used while for clover before corn, a combination of 2-4 D at a rate of 0.56 kg ai/ha and glyphosate at a rate of 1.12 kg ai/ha was used. Rolling is often practiced on high biomass cover crops as a method of flattening the crop and enhancing the ability of the planter to effectively seed a cash crop (Raper et al., 2004). Auburn University Extension recommendations (<http://www.aces.edu/pubs/pubIndexes/anrag.php>) were used to apply all fertilizers, herbicides, insecticides, and defoliants for the cash crops. Tillage was usually implemented in mid-April with the cotton being planted approximately 2 weeks later. The center two rows were harvested and weighted to obtain seed cotton and corn yield.

A three-dimensional dynamometer was attached between the tractor and the tillage implement at the time of tillage to measure tillage force. This device measured draft, vertical, and side forces required for each tillage treatment. A radar gun was used to obtain tillage speed, which was used along with draft to calculate deep tillage energy. A constant velocity of 4.5 km/h was maintained throughout the experiments.

Soil strength was determined by use of cone index measurements (ASAE Standards, 2004a, 2004b) which were obtained with the Multiple-Probe Soil Measurement System (Raper et al., 1999). These measurements were taken with all five-cone index measurements being equally spaced at a 0.19-m distance across the soil with the middle measurement being directly in the path of the shank.

Data was subjected to ANOVA using the Statistical Analysis System (Littell et al., 1996). Preplanned single degree of freedom contrast and Fisher's protected LSD were used for mean comparisons. A significance level of $p < 0.1$ was established *a priori*.

RESULTS AND DISCUSSION

SOIL PROPERTIES

Experiment 1: Cotton Production in Coastal Plains of South-Central Alabama

During 2005, an intensive sampling regime was conducted following harvest which consisted of obtaining measurements of soil cone index, bulk density, and soil moisture. Cone index showed significant main effects of

depth ($p \leq 0.001$), in-row subsoiling treatments ($p \leq 0.001$), and measurement position ($p \leq 0.001$). Also noted were significant interactions between in-row subsoiling treatments and depth ($p \leq 0.001$), in-row subsoiling treatments and measurement position ($p \leq 0.001$), and measurement position and depth ($p \leq 0.001$). When the in-row position where the shank disturbed the maximum amount of soil was examined, the spur was found to have had little effect on cone index (fig. 2). However, the differences in soil strength from increased tillage depth were clearly demonstrated with shallow in-row subsoiling failing to disrupt the hardpan profile and a root-imposing layer found at depth of 15 to 35 cm.

Bulk density measurements (fig. 2) taken at the same time closely followed the patterns found in the cone index figures with significant main effects being found for depth ($p \leq 0.001$) and in-row subsoiling treatment ($p \leq 0.01$). A significant interaction was also found to occur between depth and in-row subsoiling treatment ($p \leq 0.001$). Small differences were found as a result of the use of the spur, while differences in tillage depth were clearly noted. Largest values of bulk density were also obtained at the approximate hardpan depths noted by cone index measurements.

One possible reason for differences in cone index measurement could be explained by differences in soil moisture. Also, there was potential for the spur to increase infiltration and improve water storage. However, upon examining the data obtained for soil moisture, the only significant effect was found for depth ($p \leq 0.001$) with greatly increased values of soil moisture found for depths greater than 20 cm (fig. 2). Only a small increase in soil moisture was found for the spur which occurred only with the use of shallow in-row subsoiling. Also, shallow in-row subsoiling tended to have slightly higher soil moisture at depths lesser than 15 cm and slightly decreased values of soil moisture at depths greater than 15 cm. This result seemed reasonable as decreased infiltration would cause soil moisture to be kept shallower thus not penetrating to depths below in-row subsoiling.

Experiment 2: Cotton Production in Tennessee Valley Region of North Alabama

Cone index values taken in the spring of 2006 after in-row subsoiling treatments had been applied show little effects of the spur (fig. 3). However, differences between shallow and deep in-row subsoiling were visible as well as differences between the tilled plots and the higher soil strength found in the no-till plots. By the end of the growing season of 2006 all of the tilled plots had reconsolidated and had increased in cone index, especially between depths of 5 to 10 cm (fig. 3).

Experiment 3: Corn Production in Coastal Plains of South-Central Alabama

After harvest of the corn crop in 2005, cone index measurements showed differences in soil strength caused by the depth of in-row subsoiling. These differences were found between depths of 25 to 40 cm with deep in-row subsoiling having smaller values (fig. 4). Differences in bulk density (fig. 4 center) and soil moisture (fig. 4 bottom) were not found to be caused by either tillage depth or use of the spur. The only differences noted were due to changes in depth. It is interesting that in nearby plots associated with Experiment 1,

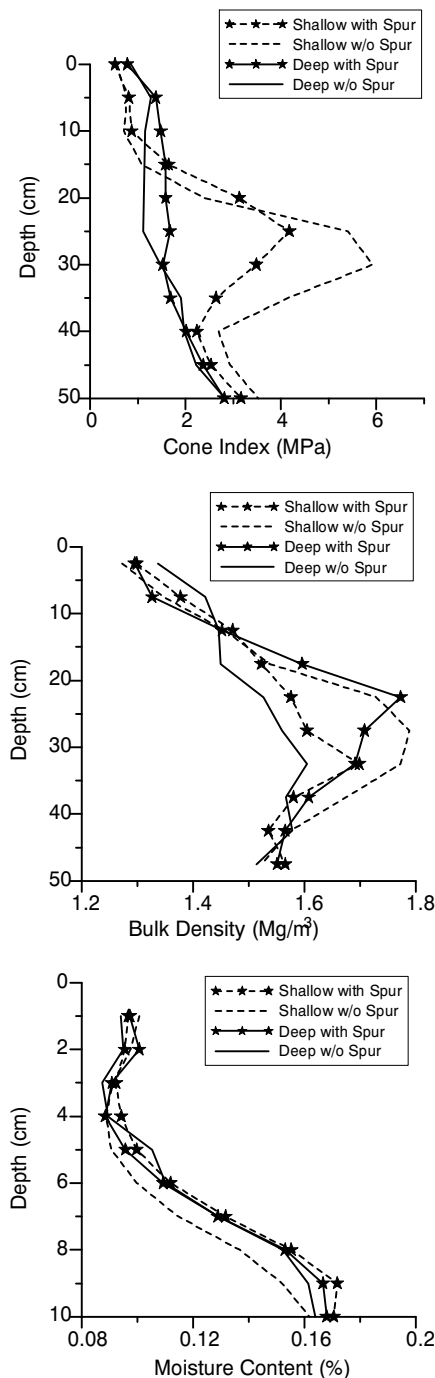


Figure 2. Soil measurements obtained in 2005 in the in-row position for experiment 1: cone index (top), bulk density (center), and soil moisture (bottom).

more distinct differences in bulk density were noted as a result of tillage depth. One possible explanation is that although the other plots were nearby, rapid changes in soil type were found in this alluvial soil as caused by flooding from the nearby Tallapoosa River.

MACHINERY

Experiment 1: Cotton Production in Coastal Plains of South-Central Alabama

Draft force was found to be similar for all years of the experiment (fig. 5) with contrasts showing significantly less

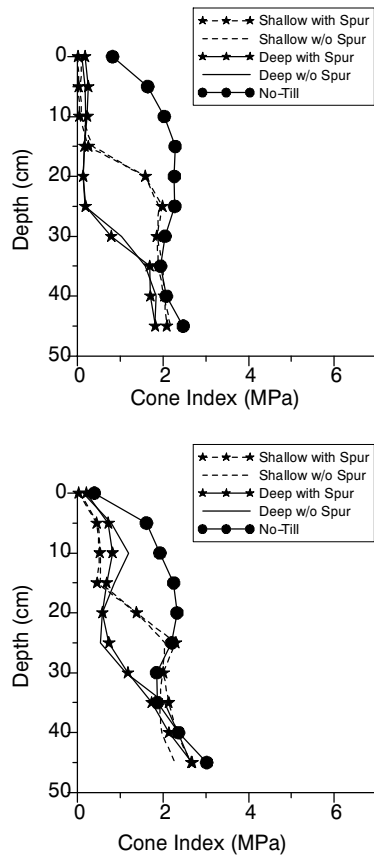


Figure 3. Soil cone index measurements obtained for experiment 2 in 2006 in the spring after planting (top) and after harvest (bottom).

force being required for shallow in-row subsoiling as compared to deep in-row subsoiling (2004, $p \leq 0.001$; 2005, $p \leq 0.001$; 2006, $p \leq 0.001$). Shallow in-row subsoiling which was conducted at approximately 60% of the depth of deep in-row subsoiling was found to require 50% of the draft force required for deep in-row subsoiling (15.5 vs. 30.9 kN). The following equation from ASAE Standard D497.4 (2003) was used to evaluate our experimental values.

$$D = F_i * [A + B(S) + C(S)^2] * WT \quad (1)$$

where

D = draft (kN)

F_i = dimensionless soil texture adjustment parameter ($F_1 = 1.0$, $F_2 = 0.7$, and $F_3 = 0.45$) and $i = 1$ for fine, 2 for medium, and 3 for coarse textured soils

A , B , and C are machine-specific parameters (226, 0, and 1.8, respectively)

S = field speed (4.5 km/h)

$$W = \text{number of rows} \quad (4)$$

T = tillage depth (23 or 30 cm)

For experiment 1, where shallow in-row subsoiling was performed at two depths (23 and 30 cm), we noted that a change in soil texture occurred with shallow layers being coarse and deeper layers being medium texture. Using data from ASAE Standard D497.4 (2003) for a narrow point subsoiler, we calculated 10.8 kN for shallow in-row subsoiling, and 22.0 kN for deep in-row subsoiling. These values were slightly reduced from the experiment values but are within the $\pm 50\%$ range advised by the standard.

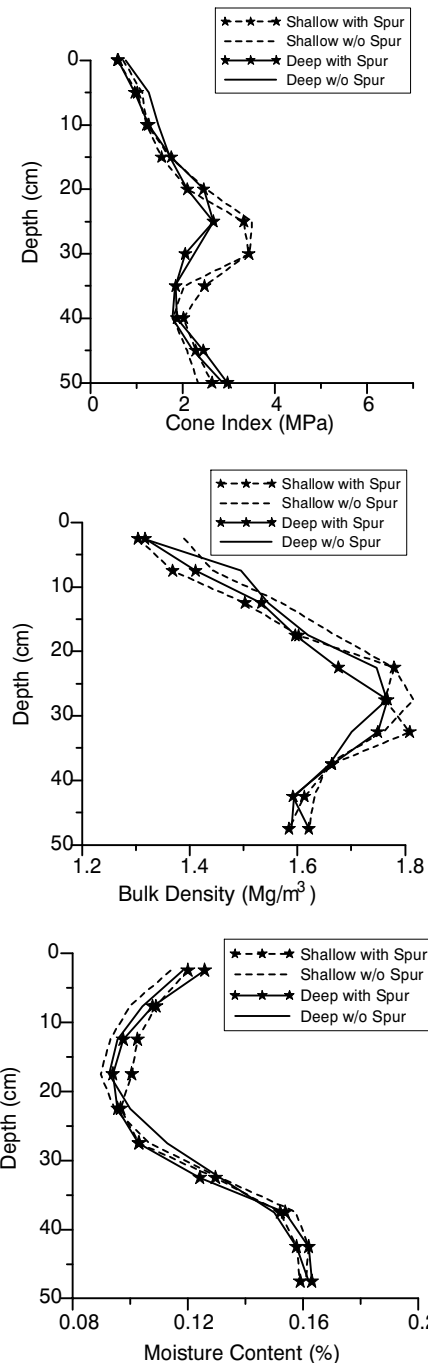


Figure 4. Soil measurements obtained after harvest in 2005 in the in-row position for experiment 3: cone index (top), bulk density (center), and soil moisture (bottom).

Rotational velocity of the spur was measured in 2006 and was found to be significantly affected by tillage depth ($p \leq 0.02$) with shallow in-row subsoiling having higher angular velocity of 239 rpm as compared to deep in-row subsoiling angular velocity of 219 rpm. At the 30-cm depth of operation, the greater amounts of soil encountered by the spur probably hindered its operation slightly and decreased its angular velocity.

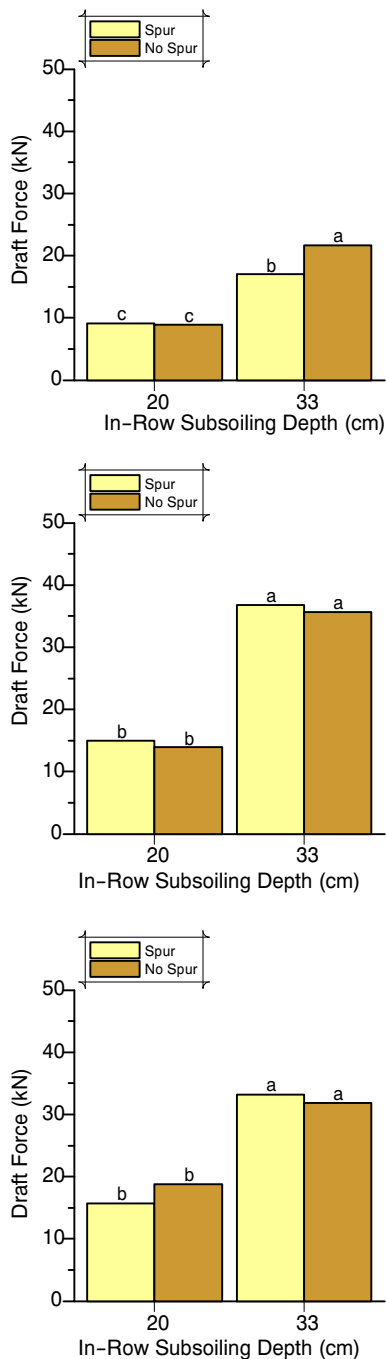


Figure 5. Draft force measurements for experiment 1 obtained in 2004 (top), 2005 (center), and 2006 (bottom). Letters indicate statistical significance (LSD0.1) within years.

Experiment 2: Cotton Production in Tennessee Valley Region of North Alabama

In 2005, draft force was found to be affected by both depth of in-row subsoiling ($p \leq 0.001$) with shallow in-row subsoiling requiring 19.6 kN and deep in-row subsoiling requiring 40.9 kN and use of the spur ($p \leq 0.06$) with the attachment requiring an additional 3.8 kN (32.2 kN with attachment compared to 28.4 kN without the attachment; fig. 6). In 2006, a similar significant effect was noted between tillage depths ($p \leq 0.001$) with shallow in-row subsoiling requiring 11.1 kN and the deep in-row subsoiling

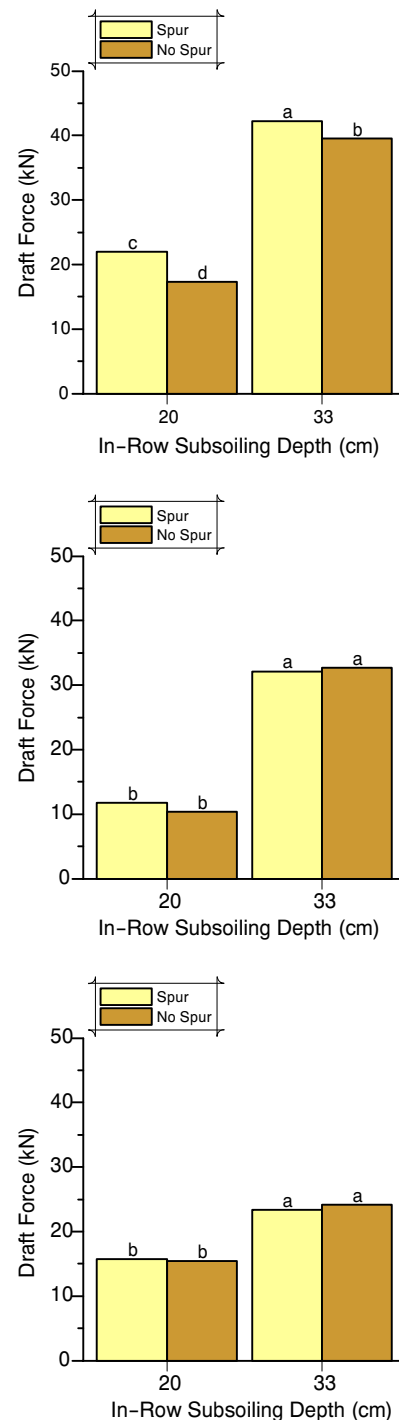


Figure 6. Draft force measurements for experiment 2 obtained in 2005 (top), 2006 (center), and 2007 (bottom). Letters indicate statistical significance (LSD0.1) within years.

requiring 32.4 kN. No differences were noted due to the use of the spur. In 2007, statistical differences were again found between in-row subsoiling depths ($p \leq 0.001$) with shallow in-row subsoiling requiring 15.6 kN and deep in-row subsoiling requiring 23.8 kN. Again, no differences were found in draft force due to the use of the spur.

Average values of draft measured over the 3-year period were 15.4 kN for shallow in-row subsoiling and 32.4 kN for deep in-row subsoiling. Draft values were greater than those measured in south-central Alabama especially for shallow

in-row subsoiling and was mostly due to different soil types found in the region. Using ASAE Standard D497.4 (2003) and assuming the shallow soil to be medium textured and the deeper soil to be fine textured (which were similar to the assumptions that were made for experiment 1 in south-central Alabama), 16.9 kN was calculated for shallow in-row subsoiling and 31.5 kN was calculated for deep in-row subsoiling. These draft values compared very favorably with our measured values.

Experiment 3: Corn Production in Coastal Plains of South-Central Alabama

In 2005, changes in depth of in-row subsoiling caused differences to be detected in draft energy ($p \leq 0.001$) with shallow tillage requiring 18.6 kN and deep tillage requiring 28.4 kN (fig. 7). In 2006, shallow in-row subsoiling required 12.2 kN which was significantly different than the deeper tillage depth of 28.7 kN ($p \leq 0.001$). In 2007, shallow in-row subsoiling was found to again require significantly reduced draft of 9.3 kN as compared to that required for deep in-row subsoiling (22.4 kN; $p \leq 0.001$). In none of the 3 years did differences in draft occur due to the use of the spur.

Average measured values of 13.4 kN were found for shallow in-row subsoiling and 26.5 kN for deep in-row subsoiling. Again referring to ASAE Standard D497.4 (2003) for a narrow point subsoiler, 10.8 kN was calculated for shallow in-row subsoiling, and 22.0 kN was calculated for deep in-row subsoiling which were more similar to our experimental values than those found for Experiment 1.

Rotational velocity of the spur was measured in 2006 and was found to not be affected by tillage depth with shallow in-row subsoiling having angular velocity of 222 rpm as compared to deep in-row subsoiling angular velocity of 224 rpm.

CROP

Experiment 1: Cotton Production in Coastal Plains of South-Central Alabama

Seed cotton yields varied substantially over the three years of the study with significant droughts occurring during the growing season in 2004 and 2006. Seed cotton yield was not affected by the use of the spur on the coarse-textured soils of the Coastal Plains in any of the three years of the study (fig. 8). The only trend that was noted concerning the spur was that slightly increased yields occurred when in-row subsoiling at a shallow depth without the spur. A plausible explanation is that increased infiltration caused by the spur could have decreased the amount of soil moisture present in the profile and available to cotton plants.

No differences in seed cotton yield were found as a result of different depths of in-row subsoiling. This result corroborates an earlier publication which indicated that no differences in seed cotton yield were found in Coastal Plains soils as a result of tillage depth (Raper et al., 2007). These data also illustrated that substantial savings in energy and fuel consumption could be saved by adjusting in-row subsoiling depth to shallower depths as deeper in-row subsoiling didn't contribute to increased yields and required substantially greater amounts of energy.

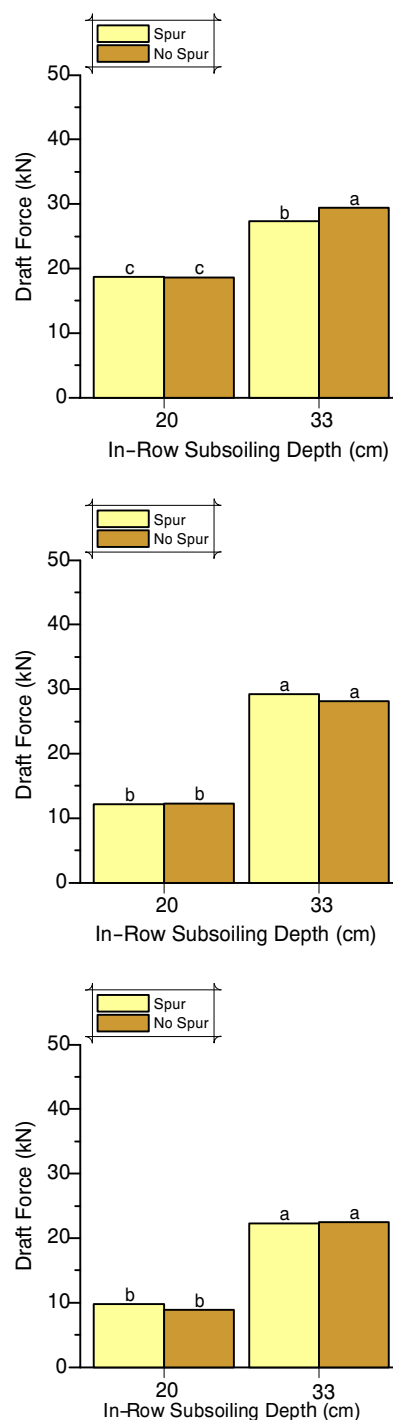


Figure 7. Draft force measurements for experiment 3 obtained in 2005 (top), 2006 (center), and 2007 (bottom). Letters indicate statistical significance (LSD0.1) within years.

Experiment 2: Cotton Production in Tennessee Valley Region of North Alabama

In 2005, the use of the spur attachment proved to be advantageous to seed cotton yield with significant increases being found due to the use of the device (3324 kg/ha for the spur as compared to 2972 kg/ha with no spur; $p \leq 0.08$; fig. 9). With adequate soil moisture in the soil profile throughout the growing season, the use of the spur improved plant rooting and increased crop yields. Also, when the use of the spur was

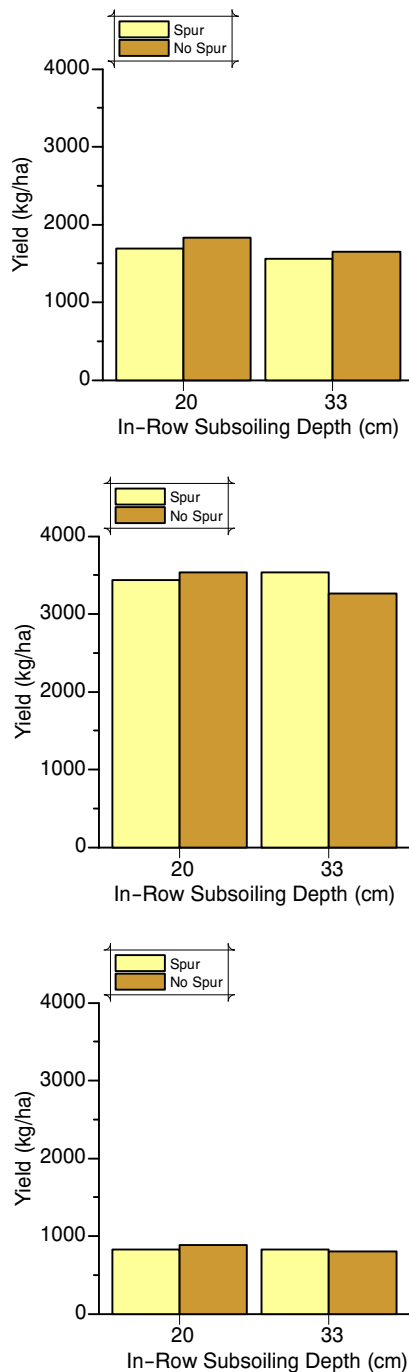


Figure 8. Seed cotton yield for experiment 1 obtained in 2004 (top), 2005 (center), and 2006 (bottom).

compared against no-tillage, the spur was found to significantly improve seed cotton yields (3324 vs. 2643 kg/ha; $p \leq 0.01$). In 2006, the use of the spur again caused improvements in seed cotton yield ($p \leq 0.1$) with the spur increasing yields from 1017 to 1170 kg/ha. During this year, no-till was found to be a better production system as compared to in-row subsoiling with no spur ($p \leq 0.04$) with no-tillage producing 1257 kg/ha. During the last year of the experiment (2007) when conditions were extremely dry, no differences were found in seed cotton yield due to the use of the spur. However, during this year, no-till caused greater seed cotton yields (1167 kg/ha) as compared to in-row subsoiling with (793 kg/

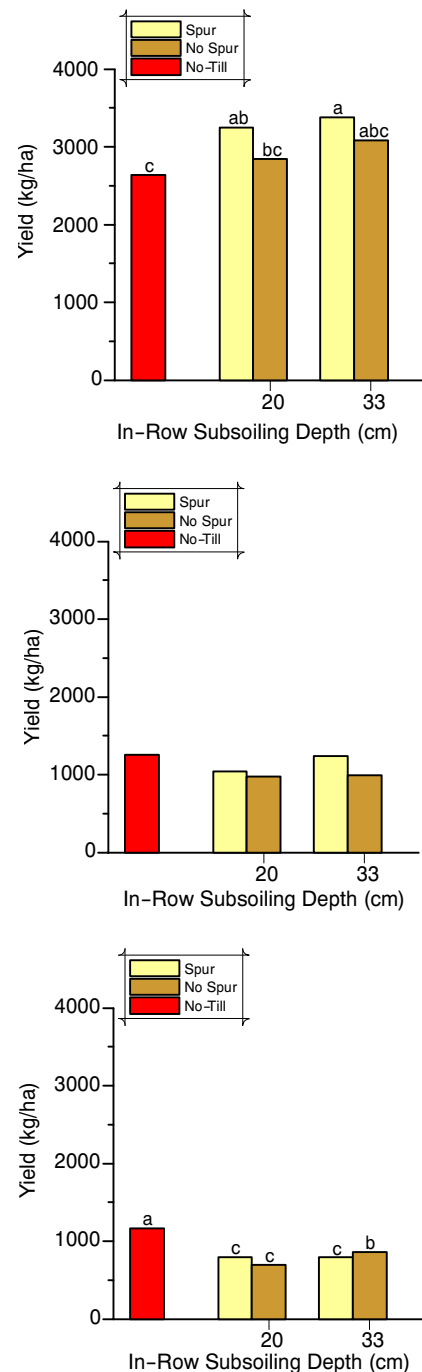


Figure 9. Seed cotton yield for experiment 2 obtained in 2005 (top), 2006 (center), and 2007 (bottom). Letters indicate statistical significance (LSD0.1) within years.

ha; $p \leq 0.001$) or without (821 kg/ha; $p \leq 0.001$) the use of the spur.

Experiment 3: Corn Production in Coastal Plains of South-Central Alabama

Excellent growing conditions prevailed in the south-central region of Alabama in 2005 and resulted in extremely high dryland corn yields for all treatments (fig. 10). Due to the excellent rainfall during this year, no differences in crop yield were found. However, the same cannot be said for the following two years of 2006 and 2007. Devastating droughts

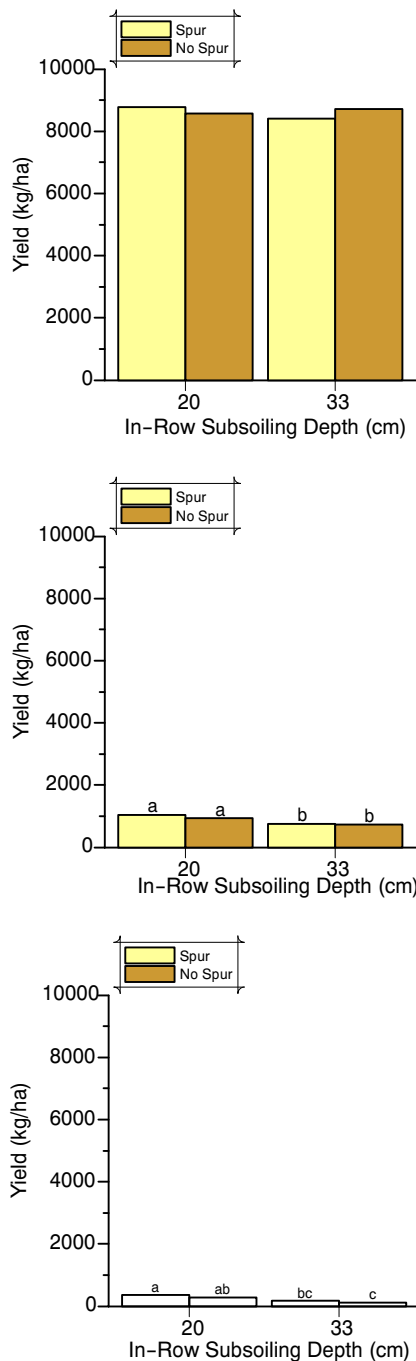


Figure 10. Corn yield for experiment 3 obtained in 2005 (top), 2006 (center), and 2007 (bottom). Letters indicate statistical significance (LSD0.1) within years.

occurred during critical periods of corn development and severely limited corn yields both years. Statistical differences were found in 2006 with shallow in-row subsoiling resulting in higher corn yields ($p \leq 0.002$) but the yields were so low with shallow in-row subsoiling producing 981 kg/ha and deep in-row subsoiling producing 742 kg/ha that they could be deemed irrelevant. The same trends existed in 2007 except that shallow in-row subsoiling only produced 270 kg/ha while deep in-row subsoiling produced 232 kg/ha ($p \leq 0.001$). However, the yields were again too small to be considered relevant.

CONCLUSIONS

- The spur was found to not have any significant effect on soil properties nor on draft forces. However, seed cotton yield in the finely-textured soil (Decatur silt loam) was found to be significantly improved in 2 of 3 years. In coarse-textured soils (Compass sandy loam) where soil compaction was more problematic but also where smearing caused by the subsoiling operation was not as readily noted, crop yields were not affected.
- The depth of in-row subsoiling is clearly noted by the cone index measurements with deeper tillage disrupting compacted soil profiles well below the depths of shallow tillage. However, deeper tillage depth did not increase corn or cotton yields. Most importantly, decreased depth of in-row subsoiling decreased tillage forces which translated into reduced energy usage and fuel consumption required for the in-row subsoiling operation.

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